A 3D Model of the Inner City of Beijing

The Application of Data Interrogation Techniques

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Abstract: This study has two major concentrations: 1) exploring methods of creating a digital city model, and 2) applying the model to study urban spatial structure, an issue of particular interest and importance to urban planners. Based on existing studies that primarily address two-dimensional (2D) urban structure, this paper focuses on the three-dimensional (3D) structure relating to the 3D urban form. Given their greater clarity and possibilities for quantitative analysis, both 3D digital urban models and GIS spatial overlay analysis methods hold tremendous potential for analysing and predicting future urban form. In this project, the Xidan Business District in Beijing's Inner City was the area selected to implement the digital-city application. Under the hypothesis that the existing urban spatial structure is determined by the city's urban planning scheme and current urban marketing forces, it is found that actual urban development does not follow the planning restrictions on zoning and building height regulations. Some contradictions and conflicts, such as building location and height, appeared in the studied district. The specific reasons for the discrepancies need to be further studied.

1 INTRODUCTION

For 800 years, the city of Beijing has been designed to function as the capital of China. The original urban planning concepts were guided by certain aspects of Chinese culture and philosophy, reflected in the urban forms preserved in the Inner City. Throughout its historical evolution, the area's urban form has been affected dramatically by socio-cultural, economic and political changes; furthermore, urban problems and conflicts have emerged. For example, the Inner City district is facing challenges due to issues of modernization and alterations in skyline shapes, landmark images, traffic patterns, and land-use allocations.

For urban planners, design practitioners and planning scholars, appropriate tools to aid urban study and the decision-making processes are needed, but these ideas have not been fully explored. A three-dimensional (3D) digital city would be such a tool; however, a digital city that can be virtually displayed and viewed in full scale would be more useful for this purpose. This paper depicts 3D visualization of a digital city, the methods used for geometric modelling, the results of the virtual models and generational processes, and one exercise in applying the model to evaluate the urban spatial structure.

2 URBAN SPATIAL STRUCTURE

Urban spatial structure is defined as an organizational representation that includes both 2D urban patterns and 3D urban forms. Since the 1960s, urban spatial structure has been one of the many foci in research exploring factors that affect the evolution of urban growth—for instance, how urban economic development would affect the functional characteristics of a city and its optimal size (Capello and Camagni 2000); how economic, housing and land reform have changed Chinese cities (Wu and Yeh 1999); and the impact of urban patterns on ecological conditions. These studies showed the significance of analyzing a city's urban spatial structure.

From the 1980s onward, cellular automata has been one of the computer-simulation methods used widely for describing urban spatial evolution and for explaining how and why cities grow (Couclelis 1997; Batty, Xie, and Sun 1999; Barredo et al. 2003). Other studies have applied information technology to construct a digital city (Blundell, Williams, and Lintonbon 1999; Pietsch, Radford, and Woodbury 2001) for visualization and urban study purposes. This research intends to develop a digital model based on virtual reality technology (Langendorf 1995; Chan, Dang, and Tong 2004) to provide an interactive simulation and analysis environment for studying the urban spatial structure. This virtual city model includes volumetric city blocks and related urban data for study. The Inner City of Beijing has been selected as the subject of study.

3 3D MODEL OF AN URBAN SPATIAL STRUCTURE

Beijing is a dynamic city that combines traditional housing, historical palaces, and modern skyscrapers together in a metropolitan environment. Currently undergoing a process of rapid growth, the city faces various urban issues that challenge planners and policy makers. Thus, it is critical to explore new possibilities and new tools that would aid urban decision making. This is the purpose of this project.

Methods for developing a digital city model have been well explored in many projects done at universities in Europe, America and Asia through the use of various geometric modeling systems (Jepson and Friedman 1998). Other methods include applying computer vision, graphic technologies, and 3D laser scanners to digitally archive historical monuments and restore cultural heritage objects (Ikeuchi 2004). Some of these projects have generated beautiful models in the virtual reality environment. However, few projects have been designed to be a full-scale display in an immersive setting. This project intends to concentrate on the digital study of urban spatial structure; thus, two models were constructed—a volumetric model implementing building height regulations and a detailed urban model displaying existing conditions with realistic building heights and appearances. Each model has both a PC and virtual-reality version.

3.1 Data Acquisition

The most interesting issues in modeling a city relate to the problems of gathering and maintaining tremendous amounts of urban data, and the accuracy of building data. The methods used to create a volumetric city model to show the planned urban volume were based on the information given on the building-height regulation map issued by the Beijing Urban Planning Commission in 1990. Figure 1 shows the map with 14 different colours representing different land-use and height restrictions. However, creating a model that represents the current city is more difficult. Particularly, the technological limitations and mobility issues of 3D laser scanners yield difficulties for scanning buildings in a large-scale urban environment, and the inaccessibility of accurate, detailed drawings from government authorities makes the data acquisition process more challenging. Fortunately, various data-acquisition methods have been tested on the city maps provided by associates at the Beijing University of Technology and on satellite photos purchased from the DigitalGlobe Company. Different algorithms were applied to the sets of building drawings provided by the Beijing Urban Planning Commission. Extra algorithms were developed in this project to serve specific purposes.

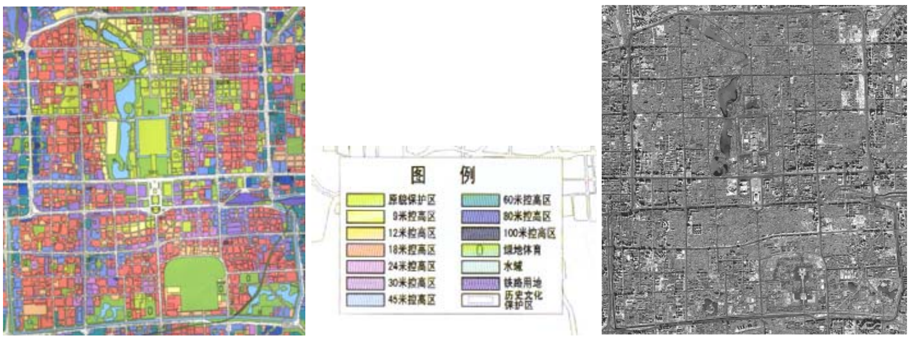

Figure 1 Building-height regulation map and satellite photo of the Inner City

One algorithm applied techniques available in remote sensing (RS) and geographic information systems (GIS) to fetch 3D information from satellite photos obtained on October 18, 2001 (see Figure 1). The satellite photos consisted of a 61-centimeter panchromatic black-and-white image (Figure 2a) and a 2.44-meter multi-spectral colour image (Figure 2b). Manipulated through the ERDAS image-processing software package, these two images were fused into a clear and colourful city image (Figure 2c). The second algorithm was to export the image into GIS to draw the 2D geometry of each building (Figure 3a) and apply the topology function to create a database including the building's ID number, area square footage, perimeter, existing height, and related city regulations (Figure 3b). The third algorithm was to calculate the existing building height of each building from the formula of H = 0.648855 * BC (Figure 3c), where BC is the distance length of building shadows measured in the satellite photos. The formula was derived from the relations among parameters of solar elevation, solar azimuth, satellite elevation and satellite azimuth. Particularly, the satellite elevation determines the length of the building's oblique projection, and satellite azimuth determines the direction of the building's oblique projection (Chan, Dang, and Tong 2004).

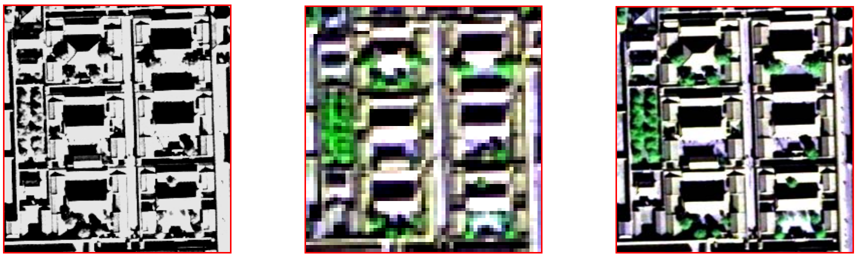

Figure 2 (a) Panchromatic Image (b) Multi-spectral image (c) Fusion image

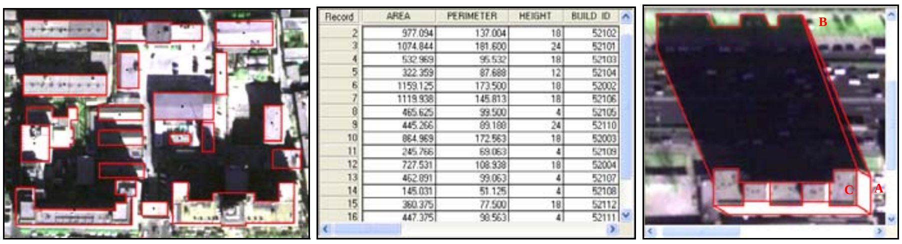

Figure 3 (3a) 2D geometry in GIS (3b) 2D data in GIS (3c) 3D information

Table 1 Examples of building-height calculation results (Unit=Meter)

Building Name	Shadow Length *(BC)*	Transform Coefficient	Calculated Height (*H*)	Actual Height	Errors
Power Building	67.207681	0.648855	43.61	44.00	-0.39
Time Square	91.738757		59.53	60.00	-0.47
Wujing Building	79.992469		51.90	52.00	-0.10
Book Store	67.857083		44.03	44.00	0.03

After the length of each building's shadow (BC) was measured from the photo image, the formula could calculate its existing height (H), which was used to convert its 2D shape to a 3D solid in GIS. Results of this method generated a digital city model with individual buildings reflected existing heights. This method was tested on four existing buildings located in the Xidan Business District. The actual values of these four building compounds' height were given by the city. Results of the eight measurements (Table 1 lists only four values) indicated that the possible errors ran from 0.03 to -0.47 meters. Thus, it is concluded that the methodology applied in this algorithm is valid and reliable.

3.2 Modeling Process

The volumetric city model was generated via this process: (1) scanning the building-height regulation map, (2) scaling it up to full scale in ACAD, creating 2D in ACAD, (3) exporting the 2D to GIS, (4) extruding it to 3D with the regulated building heights in GIS, and (5) converting the model to VRML for visual display. This model serves as an abstract representation (or a graphic representation of urban text codes) of the city (Figure 4). In the model, different colours represent the regulated building height of each block.

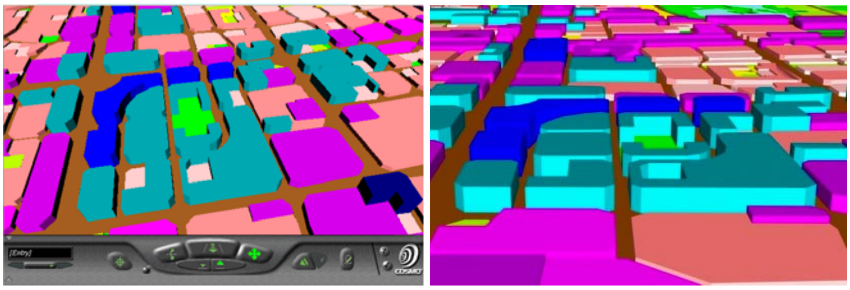

Figure 4 Volumetric model of the Inner City of Beijing in VRML format

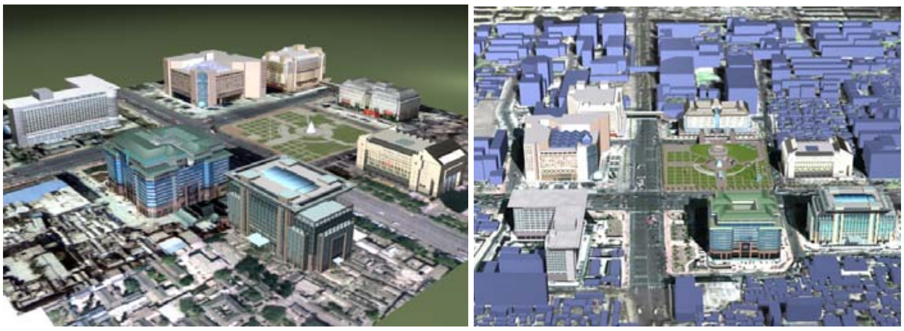

Figure 5 Detailed MAX model and combined model

The existing city model was constructed by measuring buildings' shadow length to achieve accurate measurements of height. In order to show a more realistic city vista, detailed models were constructed using digital photographs through texture mapping in 3D MAX. A photograph of every façade was taken on site and exported to AutoCAD to obtain accurate dimensions before being applied in 3D MAX to achieve a realistic appearance. Results of combining the existing city model and detailed model are shown as an example in Figure 5. This final PC model has the potential to be used as a tool or a base for studying urban design.

In terms of showing the model in virtual full scale, the PC models were converted into VRML models using OpenSG as the graphic scene generator for the virtual reality display. The VR Juggler program controls the OpenSG package to create immersive 3D graphics in the CAVE virtual environment. Combining 3D projectors, 3D goggles and a wireless tracker, a digital model can be viewed and accessed interactively in the immersive CAVE environment.

3.3 Modelling Results

The modelling processes are extremely time consuming, due to the extensive collections of photographs, maps, drawings, site surveys and building measurements needed to construct the model. The key issue, however, is balancing the various systems to obtain the maximum level of realism when the model is displayed in the CAVE (Figure 6a). This project has run numerous trials to find the optimal solution for digitizing the model accurately and showing details of the city vista realistically, to allow for the display of digital culture. A wireframe model was also created in C6 (six-sided CAVE facilities) for easy navigation (Figure 6).

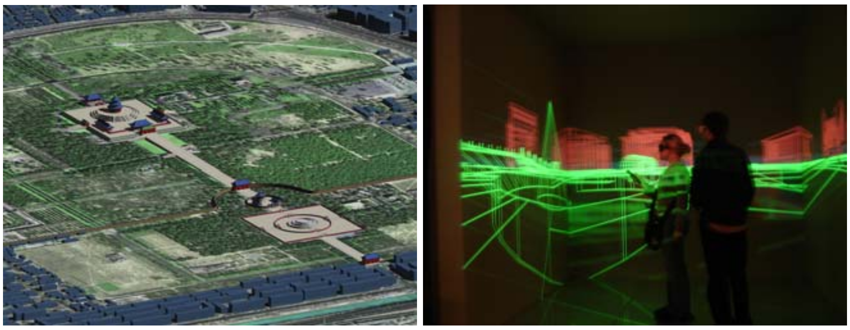

Figure 6 Temple of Heaven (left) and the wire frame of the Inner City (right)

4 APPLICATIONS OF THE DIGITAL MODEL

The applications of the two digital city models were tested in the following. For example, the Xidan Business District has an area of 2.85 square kilometres (4.5% of Beijing's Inner City area). Figure 7 shows a 2D building-height regulation map and a 3D model of the regulated form of this area. Figures 8 contains detailed 2D map and 3D model views of existing urban conditions. Images in the regulated model (Figure 7) show that the main street is wide and straight while the secondary streets are well-organized. Buildings are not very high, leaving the skyline relatively flat. Generally speaking, tall buildings are located along the main street, and low buildings are mostly on the secondary streets.

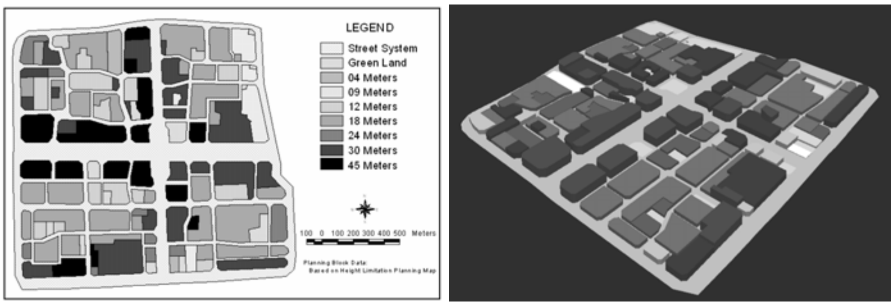

Figure 7 2D and 3D models of the regulated urban form

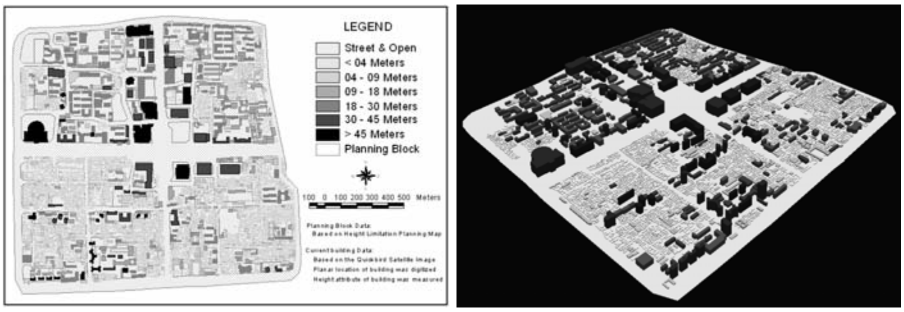

Figure 8 2D and 3D models of the existing urban form

Table 2 Statistical analysis of building-height regulations in Xidan Business District

Planning Land-use	Height (M)	Count	Sum_Area (M^2)	Percentage (%)
Green space	0	12	71406.01	4.02
Preserved	4	2	31734.65	1.78
09 M	9	5	92149.48	5.18
12 M	12	15	191196.11	10.75
18 M	18	30	629277.19	35.39
24 M	24	9	77472.97	4.36
30 M	30	22	405661.22	22.81
45 M	45	15	279438.68	15.71
Total / Average		110	1778336.3	100

Data shown in Table 2 are results obtained from the GIS database. The most prevalent item is the 18-meter block height, which occupies 35.39% of the entire district. The 30- and 45-meter heights are the second and third most common. Together, these three categories account for 73.91% of the district, making this district slightly taller than others in the Inner City of Beijing. For the Inner City as a whole, the most common regulation is the 18-meter height limit. Although these building-height regulations have been set up as planning guidelines, urban development may or may not follow such strategies. Figures 7 and 8 do show that the current spatial structure in Xidan Business District is more complex than intended. Other issues are discussed in the following sections.

4.1 Spatial-structure Analysis

Other than checking conformity to regulations and codes, digital city models can also be used to analyze the character of the urban form. For instance, although most of the buildings are low-rise, the district as a whole is not as flat as the planning scheme would suggest. This can be seen by combining the two models together to visualize the results, which show the locations of high-rise buildings are scattered, and some of them exceed the maximum regulation of 45 meters (see Figure 9).

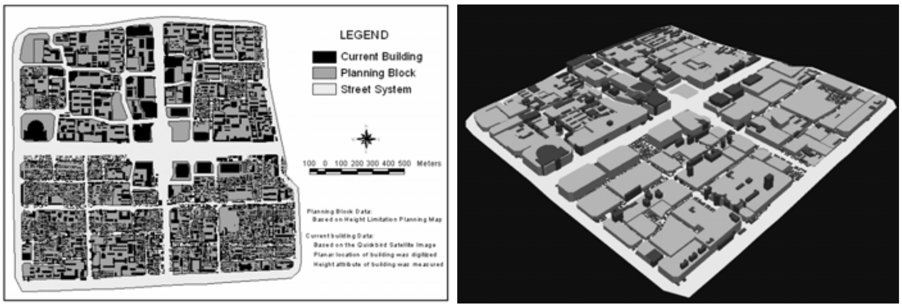

Figure 9 2D and 3D views combining the regulated and existing urban forms

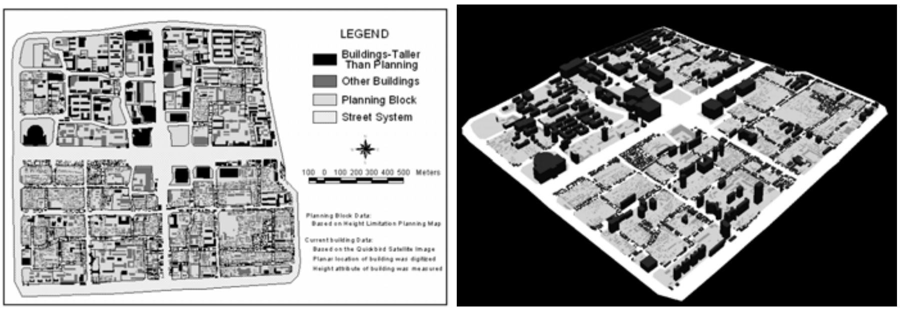

Figure 10 2D and 3D view of the buildings that are taller than planned

4.2 Contradictions

After extensive study of the GIS data sets and VR models, several contradictions between the planning regulation scheme and current situations could also be discovered. For instance, some buildings exceed the maximum building height indicated by their assigned value (Figure 10), some buildings are located outside the planned street, and some are even on green space, etc. In sum, after the urban ordinances are graphically displayed three dimensionally, the contradiction and conflict can be accurately identified. By the same token, expected outcomes could be easily visualized, evaluated, and modified.

4.3 Future Prediction

Courtyard housing is a traditional Chinese dwelling typology in Beijing. Most of the courtyard houses are located in the south part of the Xidan Business District and have a low building height of 4 meters (Figure 11). According to the planning scheme, many low-rise houses in this area (around 78% of residential in this district) will be torn down and replaced by high-rise apartments or commercial buildings. This indicates that courtyard housing will gradually disappear in some areas of the Inner City of Beijing. Based on the study, it is suggested that some historical preservation strategies should be imposed in this area for maintaining cultural heritage.

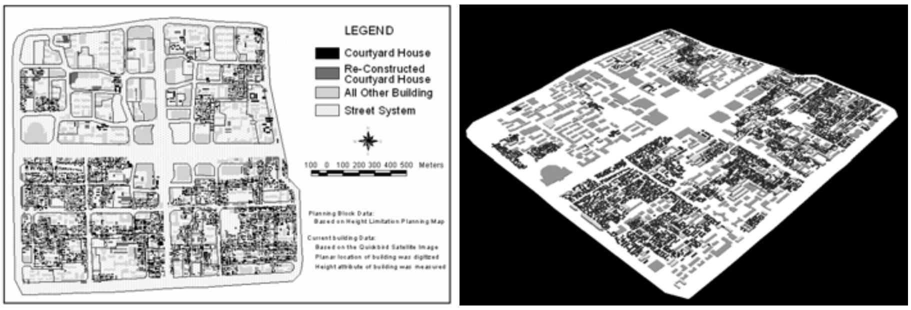

Figure 11 2D and 3D views of courtyard houses in Xidan Business District

5 CONCLUSION

The methods of creating a VR model by combining GIS and RS have shown a number of advantages for studying urban spatial structures. The model created in the GIS provides a clear database with functions for quantitative analysis on various urban issues that cannot be easily identified without the aid of a digital model. For the Xidan Business District, the urban spatial structure has been determined mainly by the urban planning scheme with a number of issues involved. It is found that the current urban development does not conform to planning restrictions on zoning and building height. Some contradictions on building location and height occurred in the studied district. The specific reasons behind the discrepancies between the urban planning scheme and the current development need to be further studied.

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